Transformation and assessment of Chinese pine pure plantations for soil and water conservation in western Liaoning Province, P. R. China

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Abstract: Western Liaoning Province is characterized by huge areas of lowly-efficient Chinese pine (*Pinus tabulaeformis* Carr.) pure plantations. How to transform these plantations has become an increasingly significant management problem. In this study, the authors summarized the approaches, which are based on close-to-nature silvicultural system, to transform the pure pine plantations. Native broadleaved trees were planted in three methods: 1) after strip clearcutting, 2) after patch clearcutting; 3) on the open forestland and the forest edge. The transformation targets and the selection of tree species were expatiated in this paper. The key techniques and their application conditions for each method were analyzed and discussed. Through investigation and contrastive analysis, the assessment was made to the stands transformed by strip method. Results showed that the mixed stands at 16 years after transformation had an obvious layered structure and the species richness of understorey vegetation increased by 23.5%-52.9%. Soil enzyme activities of urease, phosphatase and sucrase increased by 6%-142%, 46%-99% and 31%-200%, respectively. Moreover, the transformed stands could effectively control the occurrence of pine caterpillars in plantations. Consequently the transformations enhanced the function of soil and water conservation.

Keywords: *Pinus tabulaeformis;* Monoculture; Transformation; Principles and methods; Assessment

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Introduction

Soil erosion is a serious problem, which endangers agricultural and pastoral activities, and affects the sustainable development of regional economy. Recently publicized data from Second National Soil and Water Loss Remote Sensing Survey of China show that the soil erosion has occurred on 3.57 million km^2 in 1999, accounting for 37% of the nation's land area; and that erosion soil lost by 5 billion tons annual annum, which accounts for 19.2% of the worldwide total. Accordingly, erosion control has become one of preferential development programs in China 21st Century Agenda (Anonymous 1995). Planting trees is a major biological measure in regions where erosion occurs. There are about 46.67 million hm^2 of man-made forests in China, of which 22 million hm^2 were established through "Three-North Region Protective Forest System". This represents approximately 1/7 of the total plantation area worldwide and provides an extremely important protective function. However, over half of plantations are not ideally suited to ensure protective and productive functions, which are called low-efficient forests. Apparently, improving the quality of the plantations to function effectively for the ecosystem services now becomes a great challenge for Chinese forestry development (Zhang *et al.* 2000; Zhang 2001).

Due to the deforestation, western Liaoning Province (including four municipalities: Chaoyang, Fuxin, Jinzhou and Huludao) has been characterized by heavy soil erosion since the beginning of the 20th century. However, forest resources have been greatly increased by reforestation in the past five decades, especially during 1960s and 70s, and forest covers 27% of total land (Zhao 1995) compared to about 5% in 1949 (Zhang 1990). This reforestation has played an important role in restoring ecological balance and developing regional economy. Among the plantations, there are 0.533 million hm^2 of Chinese pine (*Pinus tabulaeformis* Carr.) stands, occupying about 50% of total forest area in the region. Over 90% of pine plantations are monocultures and 70% of pine plantations do not function normally.

Some problems gradually occur with the growth of forest trees. First, Chinese pine is seriously affected by a pine caterpillar. Since 1950s, three species of pine caterpillar (*Dendrolimus tabulaeformis* Tsai et Liu, *D. spectabilis* Butler and *D. superans* Butler) have been found to attack pine (Zhang 1990). The caterpillar is a very serious and destructive pest of Chinese pine. They frequently appear in outbreak populations, causing widespread defoliation of their pine tree hosts. The stand area attacked by caterpilar has increased over that time period. During mid-to-late 1990s, the affected area averaged 0.22 million hm^2 per annum, accounting for about 40% of total area of pine plantations in western Liaoning Province. The insect pest

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control costs 3–5 million RMB Yuan (8.27 RMB Yuan equals to 1 US dollar) every year, and the loss of tree volume was over 0.1 million m^3 (Data of Liaoning Province Forest Pest Control Office 1999). This insect presents a serious management problem.

Second, forest fires can be a very serious problem due to the flammable needles. Statistical data from Liaoning Province Forest Fire Control Office (1999) showed that 122 forest fires occurred in western Liaoning Province during 1987-1998, accounting for 39.5% of total forest fires in Liaoning Province at the same time. The frequency of forest fire occurrence is highest in Liaoning Province.

Finally, the ecosystem goods and services (Costanza *et al.* 1997) produced by the pine plantations are very low. The pine trees grow slowly with low timber return (e.g., 30-39 $m^3 \cdot hm^{-2}$ for 30-year-old plantations, which means annual growth volume is less than 1.3 $m^3 \cdot hm^{-2}$) and has low ability of soil and water conservation. When it rains in summer, surface runoff occurs very easily in the monocultures, which is incapable of acting as "sponges" to reduce flooding. Soil loss rates are as high as 20–25 tons per hectare per year in many watersheds forested mainly by Chinese pine in western Liaoning (Li 1991). Furthermore, in western Liaoning, as there are a few of natural forests, wildlife abundance and diversity have dramatically decreased and some wildlife are squeezed into ever smaller patches of habitat (Zhang 1990). In monocultures, it is difficult to see the traces of roe deer, wolf, pheasant, wild rabbit and wild boar, which should be common in this region.

The above-mentioned crises are, in the final analysis, caused by the simple composition and structure of the plantation ecosystems and the large area of pure plantations. The situation could not satisfy the needs for sustainable forest management for soil and water conservation. Therefore, addressing the adjustment of tree species and structure of Chinese pine pure plantations in a large area has become a great issue in the management of forests for soil and water conservation in western Liaoning Province (Zheng *et al.* 1990; He *et al.* 1994; Zhao 1995; Du *et al.* 1999). A similar problem occurs in central Europe. Norway, spruce (*Picea abies* (L.) Karst.) monocultures have replaced original mixed stands at many sites in Europe. The change has had negative consequences, such as decrease in biodiversity, damage by biotic and abiotic factors, negative impacts of pollutants, unification of management, and changes in nutrient turnover. These stands in the first or the second generation occupy a significant proportion in the species composition in many countries. Therefore, the conversion of Norway spruce pure stands to stable, close-to-nature forest ecosystems has aroused the interest of foresters and/or ecologists (Mosandl *et al.* 1999; Schütz 1999; Küßner *et al.* 2000).

Two transformations of poor pine pure plantation stands were carried out in 1982 and 1991 in Niehugou catchment, which is part of Qitian State-Operated Forestry Farm in Lingyuan, Chaoyang. More than ten broadleaf tree species were reintroduced to mix with pine, creating different types of mixed plantations. This paper illustrates the transformation principles and methods and assesses their effects. The objective of this study is to provide a scientific basis for the reasonable management of current large-area pure pine plantations and for improving silvicultural practices.

Study area

The study was conducted in Niehugou catchment (41º20'N, 119º35'E) at the Qitian State-Operated Forestry Farm, which is located in Lingyuan, Chaoyang, a hilly region at altitudes of 500-600 m. The catchment area is about 100 hm^2. The highest mean monthly maximum temperature is 25.8°C in July and the lowest mean monthly minimum temperature is -14.2°C in January. The extremely highest temperature is 36.7°C. Annual precipitation is 400-600 mm, with most falling from June to August. Normally rainfall in the driest month is less than 10 mm, occurring in winter. Annual evaporation is 1800-2100 mm, and the frost-free period lasts 140-165 days.

The primeval forests in western Liaoning Province have almost disappeared; only few fragmented forests in some areas have survived. The vegetation in the area characterizes a transition between north China flora and a temperate steppe–oak forest sub-region typical of Inner Mongolia flora (Zhao 1995). Vegetation type is primarily Chinese pine/oak mixed forest and the canopy is around 12–15 m tall. Main native tree species include *Pinus tabulaeformis*, *Quercus mongolica*, *Q. liaotungensis*, *Q. aliena*, *Acer truncatum*, *Acer mono*, *Fraxinus chinensis* var. *rhynchophylla*, *Betula davurica*, among which pine and oak trees often dominate the canopy of a forest. The understorey species are comparatively rich, including *Spiraea trilobata*, *Corylus mandshurica*, *Prunus sibirica*, *Ostryopsis davdiana*, *Zizyphus jujuba* var. *spinosus*, *Vites chinensis*, *Lespedeza davurica*, *Lespedeza bicolor*, *Cleistogenes spuarrosa*, *Cotinus coggygria*, *Thymus serpyllum*, *Spodiopogon sibiricus*, *Carex laceolata*, *Filifolium sibiricum*, *Securinega suffruticosa*, *Cleistogenes spuarrosa* and *Artemisia sacrorum*. Brown soil is the typical soil. Due to long-term water erosion, the soil is very thin and infertile, with a soil layer of 15-40 cm, organic matter content of less than 10 $g \cdot kg^{-1}$, total N of 0.3-0.5 $g \cdot kg^{-1}$, total P (P_2O_5) of 0.6-0.7 $g \cdot kg^{-1}$, and soil pH of 6.8.

Due to the deforestation, there were only several small patches of secondary forest remained in Niehugou catchment. Local people replanted pure pine plantations there in 1970, with plantation spacing 1.5m×1.5m. These plantations did not grow well as people expected. Consequently, two times of transformation were carried out in 1982 and 1991 respectively in Niehugou catchment. Through the two transformations, most monocultures became mixed stands.

In Qitian State-Operated Forestry Farm, there are nearly 2000 hm^2 of secondary forest, accounting for 20% of total

land of the whole forestry farm, and different-sized patches of secondary forest can also be found neighboring the Niehugou catchment. These secondary forests act as some of seed sources for seedlings used for transformation.

Transformation principles and methods

Transformation principles

Sustainability has become an instructional principle for the management of forest resources and ecosystems (Probst *et al.* 1991; Christensen *et al.* 1996; Toman *et al.* 1996; Noble *et al.* 1997), although there is not necessarily a universal statement of goals for all restoration projects (Ehrenfeld 2000). Based on the practice of close-to-nature forestry in central Europe, the conversion of pure stands to stable, mixed forest ecosystems is feasible (Spathelf 1997). The transformation of poor stands serves to improve the stand composition and structure by artificial measures, to enhance forest tree growth and increase ecological and economic benefits. Transformation measures should be appropriate for different stands and different sites. Because of the diversity of the poor stands, the adopted transformation measures should be different for different poor stands, and the criteria after transformation not necessarily be unified. Even so, general criteria should include: 1) pure even-aged stands should be changed into mixed uneven-aged and layered stands; 2) homogeneous landscapes should be transformed into heterogeneous landscape.

Based upon aforementioned considerations, we abstractly developed an approach of planting broadleaf trees to improve conifers (PBTIC). Early studies (Hu 1983; Chen *et al.* 1984) developed an approach of "planting conifers to conserve deciduous trees" (PCCDT) for managing the secondary forests in eastern mountain region of Northeast China. Therefore, PBTIC approach in managing Chinese pine pure plantations actually is just referring to the PCCDT method, a testified sustainable management. The central connotation of the so-called PBTIC can be expressed as follows: in the pure Chinese pine plantations, broadleaved trees are planted, which can harmoniously grow with pine trees together; meanwhile, other management measures are adopted to enhance the growth of pine trees, to increase the stability and health of plantation stands, make the transformed stands gradually regenerate through natural way, evolve to conifer and broadleaf mixed forests charactering native vegetation, and realize sustainable management of pine plantations. The raised PBTIC here is not a specific measure for transforming Chinese pine pure plantations, but rather a general principle of complete management at a large scale. It embodies a management approach of imitating natural forest development, therefore, coincident with the ideas of close-to-nature silvicultural system in central Europe (Mlinsek 1996) and ecoforestry in many parts around world (Drengson *et al.* 1997). "Planting broadleaf trees" including shrubs is an important measure to improve the stand stability and shorten forest progressive succession. "To improve conifers" provides a guarantee for speeding up the restoration of Chinese pine -broadleaf forests, vegetation typical of the region.

Transformation targets

Based upon the structure and appearance of poor stands, they were classified into three types: A) stands which are less than 40 years old stands, with an annual growth volume of lower than 2 $m^3 \cdot hm^{-2}$, and the stand area is over 10 hm^2; B) open forestlands with a canopy cover <30%, and forest edges and erosion gullies; and C) stands which seriously suffer from pine caterpillar and in which the nearly-extinct trees account for over 5% of total trees. The transformation measures are aimed at these three types of stands.

Selection of tree species

Referring to ecological stability of forests and sustainable silviculture, planted tree species should be mainly native, and the species selected should be adapted to the site (Larsen 1995). Considering the characteristics of droughty climate and poor soil in western Liaoning Province, the transformation of poor stands for soil and water conservation should increase soil organic matter and the ability of conserving soil and water, and enhance tree growth. Meanwhile, the ratio of the broadleaf trees to pine trees should be broadened in the transformed stands. Therefore, the tree species should be selected according to their drought-resistance. Additionally, leguminous and/or non-leguminous nitrogen-fixing tree species should be chosen in order to achieve the effects of soil improvement. Using nitrogen-fixing tree species to adjust the structure of the pure pine plantation is an important approach to improve soil nitrogen content, maintain high biological productivity, and fully develop multi-function of forest ecosystems. Due to their high resistance, nitrogen-fixing tree species often play roles as pioneering species during the restoration of a forest ecosystem (Wheeler 1991; Binkley 1992; Krishan *et al.* 1993; Ngulube *et al.* 1993). Therefore, we have chosen *Caragana microphylla*, *Quercus mongolica* (Its provenance came from eastern part of Liaoning), *Cotinus coggygria*, *Acer truncatum*, *Vites chinensis*, *Prunus sibirica*, *Prunus armeniaca*, *Ulmus pumila*, *Fraxinus chinensis* var. *rhynchophylla*, *Toxicodendron typhina*, *Ailanthus altissima*, and some nitrogen-fixing species such as *Robinia pseudoacacia* (an exotic species, which was introduced into China 100 years ago and has been naturalized to be native), *Lespedeza bicolor*, *Amorpha fruticosa*, *Caragana microphylla*, and *Hippophae rhamnoides* (an introduced species from North China in the 1960s, which is naturalized to be native).

Transformation methods

Strip transformation

Along the direction of contour lines, clearcutting by strip was conducted in four 12-year-old Chinese pine pure plantations in the Niehugou catchment in 1982, through

cutting ten 3-m-wide strips by a space of 6 m between each two strips, eight 6-m-wide strips by a space of 12 m betweens, four 15-m-wide strips by a space of 30 m, and two 30-m-wide trips by a space of 50 m. The cutting area accounts for 1/3 of the reserved area in general. If the cutting areas in a stand were too large, the soil erosion would easily occur. Site preparation was completed in the autumn, and tree-planting was carried out in the spring of 1983. *Cotinus coggygria*, *Caragana microphylla*, *Robinia pseudoacacia*, *Hippophae rhamnoides*, *Quercus mongolica* (directly sow the seeds), *Acer truncatum*, *Acer mono*, *Prunus sibirica*, *Prunus armeniaca*, *Lespedeza bicolor* and *Amorpha fruticosa* were planted, with space of 1.5 m×1.5 m or 1.0 m×1.0 m.

In 1991, timbers in two 22-year-old Chinese pine pure plantations were harvested by clearcutting of 25-m-wide strips. Site preparation was in the autumn, and tree-planting was carried out in the spring of 1992. Four strips of *Prunus armeniaca* and six strips of *Prunus sibirica* were replanted, with spacing of 1.0 m×3.0 m; three strips of Chinese jujube (*Ziziphus jujuba*) and two strips of cherry (*Prunus pseudocerasus*) were planted, with a space of 1.5 m×2.0 m; four strips of *Hippophae rhamnoides* were also planted, with 2.0 m×1.0 m spacing.

Cutting width is of significance for strip transformation. Our experiments showed that the tree growth in strips was related to the strip width and the distance of planted trees to the reserved pines. The strip width could affect the ability of plants to receive light. In a narrow strip, with a 3-m-width, for example, the replanted trees receive sunlight too little. Most species, such as *Robinia pseudoacacia*, *Hippophae rhamnoides*, *Prunus sibirica*, *Prunus armeniaca* and *Quercus mongolica* grow slowly due to light suppression, and the light-favored species died such as *Hippophae rhamnoides*, *Prunus sibirica*. When the strip width was over 10 m, the above-mentioned phenomenon did not occur because of abundant sunlight availability. Considering the natural regeneration of pine, the strip width would be appropriate in the range of 10-30 m because the seeds of mother pine trees in the edge of strips can disperse up to 16 m in one direction. Moreover, the distance of replanted trees to the edge of reserved pine should be over 3 m. The strip width will be 10-15 m for the mixed plantation after strip transformation, if it is primarily used for ecological effects, such as mixtures of *Cotinus coggygria* and *Caragana microphylla* with pine. The strip width will be 15-30 m if it is used primarily for economic or timber utilization.

This transformation measure is typical of the way by which the largest transformation area of pine plantation was conducted in Niehugou catchment. It is characterized by adjusting interspecific relationships in the stand. The replanted trees grow fast, and the forest crown became closed within several years of the transformation. This method is applicable to the stands that the canopy cover is over 60% and stand area is over 10 hm^2.

After the crown of broadleaved trees closed, the density of caterpillars in all transformed mixed plantations was less than 10 insects per tree. The average tree height of *Robinia pseudoacacia* planted for timber reached 7.5 m at 16 years after transformation, and *Cotinus coggygria*-pine mixed plantation formed an obviously layered structure.

Patch transformation

Being different from the strip transformation method, the patch transformation was carried out by cutting different sizes of patch of pine trees in two 12-year-old pure Chinese pine plantations in Niehugou catchment in 1982. The cutting area accounts for 1/3 of the reserved area in a plantation in general. Site preparation was made in the autumn, and economic tree species, such as *Hippophae rhamnoides*, *Prunus sibirica*, *Prunus armeniaca*, and timber tree *Robinia pseudoacacia* selected were planted in the spring of 1983, with space of 1.5 m×2.0 m.

The size of the reserved patches is one key to this method. Field investigation indicated that pine trees were not susceptible to caterpillars in small patches (the size is often smaller than 3-5 hm^2) of pure pine stand, which were in a mosaic pattern with the stands consisting of other broadleaved species (Zhao 1995). It is not advantageous for management if the reserved patches are too small, but the mixed plantation consisting of large pine patches and other tree species do not differ significantly with pure plantation, and is easily attacked by caterpillars. Therefore, we suggest that the suitable size of patches of pure stands is 2-3 hm^2.

This method is suitable to plantations that grow in plain topography and good site condition. The vegetation can restore quickly and soil and water are unlikely to lose after the plantation is transformed. In addition, the stand canopy coverage is over 60%. The litter depth in the patch of *Amorpha fruticosa* transformed in 1982 reached 10 cm, which effectively controls the soil erosion. The economic trees planted such as *Hippophae rhamnoides*, *Prunus sibirica* and *Prunus armeniaca* are in full fruiting period.

Replantation in open forestland

Including forest edges and erosion gullies, the open forestlands were replanted with shade-tolerant tree species in the Niehugou catchment in 1982. After site preparation, *Acer truncatum*, *Quercus mongolica*, *Robinia pseudoacacia*, *Cotinus coggygria* and *Amorpha fruticosa* were planted, creating an anomalous conifer-broadleaf mixed plantation. This method is suitable for the poor stands with low crown density and uneven distribution of trees. The purpose of applying this method is to increase the stand density reasonably and improve the stand structure.

Assessment of transformed stands

Methods

Plot establishment

In this report, the assessment is made only to the stands

transformed by strip method, based on seven plots established in 1993. Each plot was 20 m×20 m in size and comprised 112–130 trees. The pine trees in each plot were planted in 1970 and broad-leaved species were introduced in 1982. The changes in stand structure, composition and soil characteristics were investigated in 1998 (Table 1).

Vegetation assessment

Understorey vegetation assessments within the stands were conducted by randomly sampling 20 subplots with a size of 1 m×1 m within each plot. All woody and herbaceous species were identified and counted, and meanwhile the number of pine seedlings (not including current year old seedlings) also was counted. The sum of species number in total 20 subplots of each plot represents species richness of each stand; and the sum of seedling number in total 20 subplots of each plot multiplied by 500 represents the seedling density per hm^2 of each stand. Percentage of ground cover was estimated. Litter depth for each plot was recorded as the mean of 5 times for measuring. One sampling point was at the center of the plot, and four more were equidistant between the center and the corners of the plot. Forest floor samples were collected at the same locations with a 1-m^2 frame, and weight of forest floor materials was determined on the spot.

Table 1. Investigations of transformed stands and untransformed stands of *Pinus tabulaeformis*

Stand type	Slope degree (°)	Stand density /trees · hm^{-2}	Number of pine trees	Height of pine trees /m	DBH /cm	Litter depth* /cm	Forest floor biomass* /g · m^{-2}
Hippophae rhamnoides –pine	10	3250	1225	6.0	9.3	2.4^{de}	395^{c}
Robinia pseudoacacia –pine	4	2800	1250	6.3	10.4	2.2^{cd}	500^{d}
Acer truncatum –pine	10	3025	1125	6.4	9.5	1.8^{bc}	275^{ab}
Quercus mongolica –pine	11	2875	1050	5.8	8.9	1.8^{b}	310^{bc}
Cotinus coggygria –pine	5	3125	1025	6.3	9.7	2.5^{e}	550^{e}
Caragana microphylla –pine	3	3100	1000	6.9	10.7	2.6^{e}	630^{f}
Pine (control)	9	3175	3175	4.6	6.8	1.5^{a}	230^{a}

Notes: DBH: Diameter at breast height of pine trees. * Values within column followed by the same label are not statistically different at p =0.05 by SNK test (The same as in Table 3).

Soil biology

Soil improvement effect is an important aspect to assess the plantations for soil and water conservation and soil enzyme activity is one of the most important indicators expressing soil fertility (Bandick *et al.* 1999). Therefore, we investigated the activities of three important soil enzymes: urease, phosphatase and sucrases. Five replicated cores of soil (2.5 cm in diameter, 20 cm in depth) were taken at the same locations as litter sampling in each plot. Core samples were composed within each plot and manually homogenized in the laboratory. The composite samples were air-dried, ground to pass through a 1-mm sieve and stored for enzyme activity analysis. Colorimetry was used to determine the activities of urease, phosphatase and sucrases (Yan 1988).

Pest assessment

The three pine caterpillars are defoliators feeding on pine needles. Severe defoliation has an impact on the growth of the pine trees, even leads to tree mortality. In northern China, there are two phases to the life cycle requiring 2 years to complete (Chen 1990).

We observed caterpillar density and the rate of attacked trees on these plots for five years, but did not carry out taxonomic identification of the three caterpillars. To estimate insect density, 11 trees in two diagonal lines were investigated within each plot in late May or early June of each year when the feeding of the caterpillars was very large. We chose four standard first-grade branches (first-grade branches grow on the stem) and carefully count the number of caterpillars. The average of caterpillars from four branches multiplied by the total branches in each tree represents the insect density of a tree. Damage assessment was based on estimates of defoliation if necessary.

Statistical analysis

Data were analyzed using the General Linear Models Procedure (PROC GLM) of version of 11.01 of the SPSS software package (SPSS Inc., Chicago, Illinois, USA). Litter depth and forest floor biomass of 28-year-old *Pinus tabulaeformis* stands containing various 16-year-old broad-leaved species were analyzed by one-way ANOVA, and also insect density and rate of attacked trees were analyzed by a one-way ANOVA involving different plots. In cases where there was a significant difference at 0.05, Student-Newman-Keuls (SNK) test was used for multiple comparisons.

Results

Change of stand composition and structure

Structure and plant species diversity express the characteristics of forest stands. The structure of pure pine stands was simple and unlayered, while the transformed stands have an obvious layered structure due to the growth of the planted trees. Understory cover obviously increased, and the number of plant species in the mixed stands at 16 years after transformation was higher than that of the pure pine stand (Fig. 1). Both shrub and herbaceous species

increased by 23.5%-52.9%, indicating that mixed stands could improve the environment by altering the availability of soil nutrients, water, or sunlight, and thus favor the invasion and colonization of other species. These species might come from seeds dispersed from nearby secondary forests by birds and/or by wind. The transformation of Chinese pine monocultures into mixed stands serves as a kind of catalytic effect in restoring native biodiversity (Guariguata *et al.* 1995; Parrotta 1995). Meanwhile, more Chinese pine seedlings over one-year old of natural regeneration in the transformed stands were observed than in monoculture where the seedlings seldom were observed. The density of seedlings in mixed stands reached 7 000-13 000 individuals per hm^2, while only 1000 individuals in the pure stand (Fig. 2). Some saplings with 1-2 m tall were also found in the mixed stands, but not in the pure pine stands.

The litter depth and biomass in the pine mixed stands after transformation by replanting broadleaf tree species were significantly (p<0.05) higher than that in non-transformed pure pine stands with an exception of the litterfall biomass in *Acer truncatum* -pine stand (Table 1), which was apparently related to the increasing litterfall. The increasing litter depth and ground surface roughness, on one hand, could prevent raindrops from directly hitting the surface and destroying soil particles, slow the speed of surface runoff and the formation of erosion, thus alleviating the intensity of soil and water loss and availability to rainfall leaching. On the other hand, the litterfall cover could restrain evaporation of topsoil, thus decreasing useless consumption of water. Undoubtedly, the increase in litterfall is advantageous for conserving soil and water for forestland in arid and/or semi-arid region.

After transformation, the height and diameter of pine trees in mixed stands respectively averaged 5.8-6.9 m and 8.9-10.4 cm (Table 1), increasing 26%-50% and 31%-53% than those in the control stand, with volume increment over 200% of individual trees.

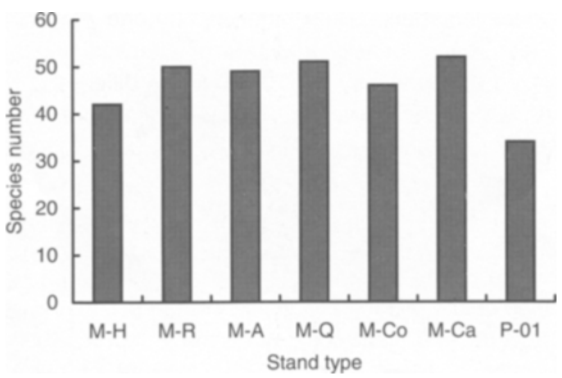

Fig. 1 The change of understory species in different mixed stands at 16 years after transformation

M-H: *Hippophae rhamnoides* -pine; M-R: *Robinia pseudoacacia* -pine; M-A: *Acer truncatum* -pine; M-Q: *Quercus mongolica* -pine; M-Co: *Cotinus coggygria* -pine; M-Ca: *Caragana microphylla* -pine; P-01: Pine (control).

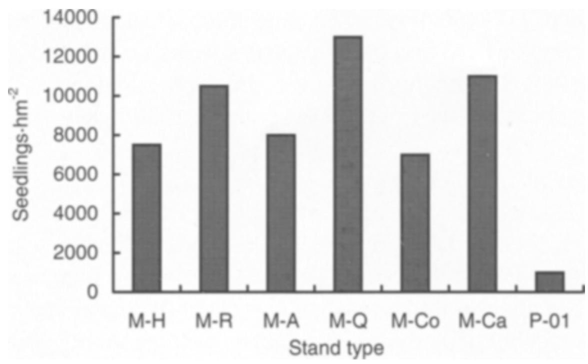

Fig. 2 The density of pine seedlings in different mixed stands at 16 years after transformation

Change in soil enzyme activity

Forest soil is a living system where all biochemical activities proceed through enzymatic processes (Kiss *et al.* 1975). Enzymes have been suggested by some researchers as potential indicators or monitoring tools to assess soil quality (Bandick *et al.* 1999) and bioremediation activities (Margesin *et al.* 2000). In all soil enzymes, sucrase is an important enzyme representing biological activity of soil. It is related to the content of organic matter, nitrogen and phosphorus, the amount of microorganism and the intensity of soil respiration, and it is thereby often viewed as an indicator for evaluating soil curing degree and fertility level. Urease activity is often used to represent the status of soil nitrogen, and is related to the contents of soil organic matter, total nitrogen, hydrolysable nitrogen and available phosphorus. Phosphatase promotes the hydrolysis of organophosphate, and its activity is, to a certain extent, determined by the content of humus and available phosphorus, and the quantity of microorganisms decomposing organophosphate, and can act as an indicator evaluating the direction and intensity of biological transformation of soil phosphorus (Burns 1982; Tabatabai 1994).

The activities of three enzymes in broadleaved-pine mixed stands were all higher than those in pure pine stands. Compared with pure pine stands, the mixed stands increased urease activity by 6% to 142%, phosphatase by 46% to 99% and sucrase by 31% to 200% (Table 2). Zhao (1995) stated that the mixed stands have abundant litter, which can be decomposed into humus by microorganisms. As a result, the physical and chemical properties of soils in mixed stands were greatly improved with increased soil organic matter content and soil enzyme activity. Conversely, the decomposition rate of litter in pure conifer stands is slow. Moreover, the high acidity of the soil is disadvantageous to the improvement of soil fertility, resulting in low enzymatic activity. Our study suggested that the transformed conifer-broadleaf mixed stands could produce a better effect on soil amelioration compared with non-transformed pure conifer stands.

Table 2. Soil enzyme activities in transformed *Pinus tabulaeformis* stands

Stand type	Urease[1)]/mg	Increment (%)	Phosphatase[2)]/mg	Increment (%)	Sucrase[3)]/ mg	Increment (%)
Hippophae rhamnoides -pine	14.35	41.38	206.57	82.82	503.39	179.89
Robinia pseudoacacia -pine	10.80	6.40	196.51	73.92	410.37	128.17
Acer truncatum -pine	16.04	58.03	159.80	41.43	329.51	83.21
Quercus mongolica -pine	20.12	98.23	223.96	98.21	537.68	198.96
Cotinus coggygria -pine	24.60	142.36	165.03	46.06	342.56	90.47
Caragana microphylla -pine	14.64	44.24	224.89	99.04	235.03	30.68
Pine (control)	10.15	-	112.99	-	179.85	-

Notes: 1), 2) and 3) represent the amount which was measured in milligram with the content of NH_3-N, phenol and glucose per 100 gram dry soil after 24 hours cultivation, respectively.

Inhibition on caterpillars

In western Liaoning Province, the simple composition and structure, and the large area of pine monocultures lead to caterpillar outbreaks. After the pure pine stands were transformed into conifer-broadleaved mixed stands, resulting in the increase of plant species biodiversity and population density, accordingly, the predatory and parasitic enemies and their population density increased, which induced an obvious change in the survival environment of caterpillars. The caterpillars and eggs are attacked by many parasites (e.g., *Trichogramma dendrolimi*, *Telenomus dendrolimusi*), some birds (e.g., great tit) and some diseases (e.g., cytoplasmic polyhedrosis virus, *Beauveria bassiana*) (Han 1982). Furthermore, the obstruction of different tree species in mixed stands and the heterogeneity of foods reduced the damage of caterpillar insects. Investigation on the occurrence of caterpillars during 1993-1997 showed that average insect density and the rate of attacked trees in the mixed stands significantly (p<0.05) differed with those in the pure stand (Table 3). The average insect density in each mixed stand ranged from 0.90 to 1.48 insects per tree, and the rates of attacked trees ranged from 18.20% to 25.46% during 1993-1997, while insect density in non-transformed pure stand reached 9.64 insects per tree, and the rate of attacked trees averaged 72.70%. The average insect density and the rate of attacked trees in the mixed stands from six mixed stands decreased by 84% and 63%, respectively. Both insect density and the rate of attacked trees did not show significant difference among different years from 1994 to 1997, while the two indexes from the years of 1994 to 1997 were different with those in 1993. In general, when population density is less 10 individuals per tree and the rate of attacked trees is less than 30%, no evident damage is made to the stands (Chen 1990); while the two indexes are over 30 insects/tree and 70% respectively, and pest outbreak is rampant (Han 1982). Our observation indicated that, after transformation, the mixed stands could effectively inhibit the occurrence of pine caterpillar. Although the pure pine stands slightly suffer from damage in 1993, the damage by caterpillars was greatly inhibited in the Niehugou catchment, and no apparent disaster took place during 1993–1997, contributing to two times of transformations in 1982 and 1991. The statistical data from Forest Pest Control Office of Liaoning Province in 1999 showed that the occurrence area of caterpillar averaged 0.22 million hm^2 per annum in western Liaoning Province during 1995-1998. The cost for caterpillar control reached 3-5 million RMB Yuan every year, and the loss of tree volume was over 0.1 million m^3. There are about 0.5 million hm^2 of Chinese pine pure stands in western Liaoning Province. If all those pine plantations were successfully transformed into mixed stands without any artificial control measures adopted, much money spent in caterpillar control would be saved every year.

Table 3. Insect population density and rate of attacked trees transformed stands of *Pinus tabulaeformis* during 1993-1997

Stand type	Population density (insect/tree)	Rate of attacked trees (%)
Hippophae rhamnoides -pine	1.08[a]	20.00[a]
Robinia pseudoacacia -pine	1.48[a]	25.46[a]
Acer truncatum -pine	1.42[a]	25.46[a]
Quercus mongolica -pine	0.90[a]	18.20[a]
Cotinus coggygria -pine	1.28[a]	21.82[a]
Caragana microphylla -pine	0.92[a]	18.20[a]
Pine (control)	9.64[b]	72.70[b]

Notes: Values within column followed by the same label are not statistically different at p =0.05.

Overall, from a long-term viewpoint, transforming the composition and structure of monocultures to stable and healthy ecosystems is a basic way to control the outbreaks of caterpillars. At the landscape level, the desired condition after implementing transformations should be one of healthy, productive, and diverse ecosystems that are dynamic and resilient to disturbances to their composition, structure, and processes of their physical and biological components.

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